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14. ABSTRACT

The primary goal of this project was to integrate and demonstrate multiple levels of autonomous decision making capabilities on an autonomous underwater vehicle (AUV). These capabilities are (1) in-situ mission modification and planning; (2) vehicle control to optimize maneuvering, manage the power consumption, and maintain vehicle safety; (3) autonomous obstacle and terrain recognition; and (4) autonomous adjustments in the sonar line-ups and vehicle operating modes to optimize the sensing performance. This project supports the ONR iPUMA project in which ARL-UT is developing a wide-area search and obstacle-avoidance ahead-looking sonar (ALS) system to be integrated on a WHOI 12-3/4" AUV. The autonomous capabilities developed in this project will enable the AUV with an iPUMA ALS system to adapt to changing mission needs, environmental conditions, vehicle status, and sensor performance.

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Final Report
Title: Integrated Mission, Vehicle, and Sensor Control of the iPUMA AUV

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LONG-TERM GOALS

This report represents one part of a three-institution collaborative effort. The additional principal investigators are: Charles Loeffler, Colin Bown, & Mike Revesz, Applied Research Labs, University of Texas at Austin, and Terry Huntsberger,, Autonomous Systems Division, Jet Propulsion Laboratory, California Institute of Technology.

The primary goal of this project is to integrate and demonstrate multiple levels of autonomous decision-making capabilities on an autonomous underwater vehicle (AUV). These capabilities are (1) in-situ mission modification and planning; (2) vehicle control to optimize maneuvering, manage the power consumption, and maintain vehicle safety; (3) autonomous obstacle and terrain recognition; and (4) autonomous adjustments in the sonar line-ups and vehicle operating modes to optimize the sensing performance. This project supports the ONR iPUMA project[1] in which ARL:UT is developing a wide-area search and obstacle-avoidance ahead-looking sonar (ALS) system to be integrated on a WHOI 12-3/4" autonomous underwater vehicle (AUV). The autonomous capabilities developed in this project will enable the AUV with iPUMA ALS system to adapt to changing mission needs, environmental conditions, vehicle status, and sensor performance. While both the ALS sensor and the AUV have their own inherent autonomous capabilities, an additional level of autonomous behavior will be provided by NASA-Jet Propulsion Laboratory's CARACaS intelligent autonomous control architecture that will maintain a higher level of situation awareness and mission performance assessment. After development, simulation, and integration of the autonomous components, this project will demonstrate a set of intelligent behaviors including obstacle and terrain avoidance, terrain following within constricted environments (such as a harbor), real time ALS optimization via sensor mode selection and AUV operation, and on-the-fly mission modification based on in-situ sensor performance assessments.

OBJECTIVES

The objective is to develop a set of autonomous behaviors that will increase the capabilities of this class of AUV's in the areas of obstacle avoidance, area survey, and mine detection. To show these capabilities, the WHOI/JPL/ARL team proposes to address 3 mission areas, obstacle avoidance, area search and survey, and restricted waters penetration with 3 corresponding final demonstrations;

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[1] Integrated Precision Underwater Mapping, N00014-00-G-0450-0031

- A demonstration is planned to show the capability of autonomous avoidance obstacles. These will includes discrete objects, such as buoys and pilings, as well as extend obstacles, such as escarpments and piers while adapting the vehicle's path and mission profile to the changing information.
- A demonstration is planned to execute a large area clutter search of a potential amphibious landing zone in a complex sub sea environment; autonomous selection of a likely assault lane in that zone; and a hi-resolution mine detection and classification survey of the selected lane. This mission will be demonstrated with an offshore ingress and egress to demonstrate long-range autonomy of a robotic asset.
- Another demonstration is planned to highlight the capability of autonomous penetration of inland waters from well offshore, detailed hydrographic reconnaissance, and final egress to an offshore location for recovery.

APPROACH

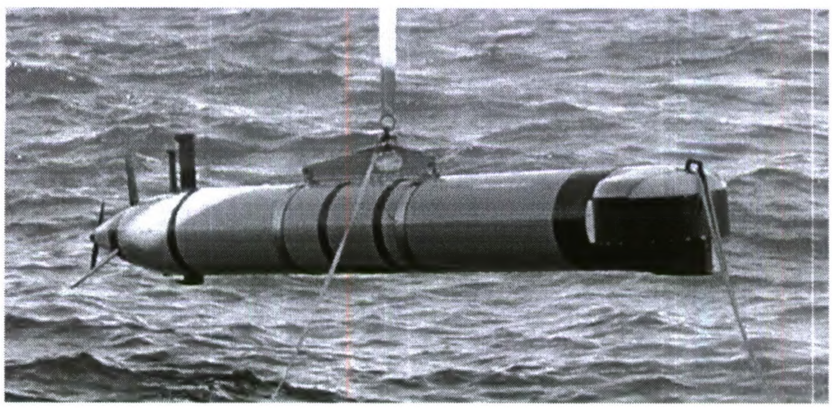

Figure 1: REMUS-600 with iPUMA sensor installed, during sea trials at ARL-UT test facility.

The Woods Hole Oceanographic Institution (WHOI) Oceanographic Systems Lab (OSL) is responsible for the development and operation of the REMUS-600 vehicle. Sensor and processor integration will be performed at WHOI, followed by local field trials. WHOI has developed a hardware vehicle simulator for use by ARL and JPL programmers for preliminary design and testing of the autonomous controller. This simulator includes the RECON interface protocol, also developed at WHOI, which allows the autonomous control processor to take over control of the UUV, while the UUV controller monitors progress, performs all low level attitude and depth control, and protects the system in the event of an autonomy failure. All vehicle engineering data is logged as in a normal mission, allowing the autonomy developer the capability to post process the mission data for analysis of performance. Extensive field trials and experimentation will be first performed at the ARL-UT Lake Travis test facility, to be followed by ocean trials and demonstrations.

WORK COMPLETED

During FY07, WHOI has participated in meetings at ARL-UT to define the system interface specifications required to interface the JPL autonomy processor and the iPUMA sensor to the REMUS-

600 RECON interface. This interface allows an external processor to take control of the vehicle. WHOI has provided ARL and JPL with the preliminary ethernet communication protocol document describing the RECON interface. In addition, WHOI developed and fabricated a vehicle simulator allowing for bench-top integration and simulation of vehicle control via the RECON interface. This simulator has been delivered to JPL. JPL used this simulator to develop and test vehicle control algorithms related to this program.

During FY08, WHOI has performed software development for the integration of the JPL autonomy processor and the iPUMA sensor to the REMUS-600 RECON interface. This interface allows an external processor to take control of the vehicle. WHOI has provided support to assist ARL and JPL with the RECON interface in simulation.

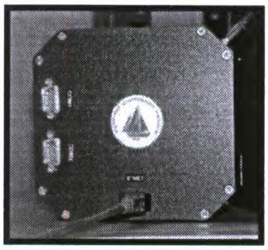

Figure 2: REMUS-600 simulator

During FY09, WHOI has provided hardware and software support to the ARL-UT operations team, including the actual integration of the JPL processor on the iPUMA REMUS-600 and preliminary operational trials at the ARL Lake Travis test facility. ARL-UT has performed multiple operations with the system, including the installation of the JPL Autonomy processor. WHOI has provided training, software updates and enhancements as required. In addition, WHOI has provided general vehicle support and upgrades.

During FY10, WHOI provided hardware and software support as needed to the ARL-UT operations team. ARL-UT has performed multiple operations with the system, including the installation of the JPL Autonomy processor. WHOI has provided software updates and enhancements as required. In addition WHOI has provided general vehicle support and upgrades. WHOI also used this funding to provide integration and operational support related to the SSAM (Small Synthetic Aperture Minehunter) testing, as requested by ONR. This testing took place at WHOI and as part of the Frontier Sentinel Exercise that took place in May, 2010 at Nofolk, VA. Follow on testing was also performed at WHOI during August, 2010 in preparation for a Navy test and evaluation event planned for October, 2010.

All work was completed prior to FY11, and the project officially closed on 12/31/2011.

RESULTS

An early result of this project has been the development of a useful vehicle simulator for autonomy developers. The simulator greatly increases the productivity of software development by allowing all preliminary testing to be accomplished in the office, such that when the controller is actually implemented in the real vehicle, nearly all problems have been corrected.

At sea testing with the integrated JPL autonomy control processor occurred in FY09. Also during FY09, the system took part in the Talisman Sabre exercise held in Australia during July, 2009, although WHOI personnel did not participate, other than as remote support.

IMPACT/APPLICATIONS

These demonstrated capabilities will greatly advance the utility of robotic undersea systems for military applications. In addition to the 3 demonstrated capabilities, there are a number of immediate, potential, and long-term. One of the immediate benefit is a platform to test and develop basic autonomous operations and new tactics. This will lead to a number of advanced mine-hunting capabilities including a wide area search, obstacle avoidance with look-ahead planning, area mapping, and adaptive path planning. Another benefit is the collection of data from (optional) multiple sensors at multiple look-angles for the same regions of the sea floor would be extraordinarily valuable to improve the understanding of background reverberation noise characteristics. These benefits cover both operational and scientific regimes.

TRANSITIONS

This technology has the potential to transition into a number of ongoing mine counter measure programs involving NAVSEA, EOD, and the Mine Counter Measures Squadron. In addition, autonomous control technology is expected to transition to NAVO programs for deep water survey missions.

RELATED PROJECTS

Acoustic and Magnetic Detection, Localization, and Classification of Proud and Buried Mines Using Light Weight AUV's, ONR Award Number: N00014-07-1-0064.

PUBLICATIONS

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T. R. Clem, J. T. Bono, P. S. Davis, D. J. Overway, L. Vaizer, D. King, A. Torres, T. Austin, R. P. Stokey, and G. Packard, "INITIAL BURIED MINEHUNTING DEMONSTRATION OF THE LASER SCALAR GRADIOMETER OPERATING ONBOARD REMUS 600", Proceedings, Oceans 2006, Boston, MA, September 2006.